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TABLES FOR DETERMINING THE VOLUME OF BLACK SPRUCE[1]

R. M. BROWN

Tree volume tables for black spruce, *Picea mariana,* based on data collected in Minnesota are not available. Black spruce is found in many swamps in the northern part of the state and is in great demand for pulpwood. The need for volume tables to estimate these stands has long been apparent.

The harvesting of a black spruce stand on the Cloquet Forest Experiment Station offered an opportunity for the necessary measurements for the preparation of such tables. This was a pure stand between 100 and 110 years old one foot from the ground. In general, it was similar to many black spruce stands occurring in swamps of northern Minnesota.

FIELD METHODS

Tree Measurements

The tree measurements upon which the volumes in the tables are based were taken during the winter of 1928. The diameters outside of bark were measured by means of calipers at one foot, 2, 3, 4.5, 9.15, 12, 17.3 feet above ground and at 8.15-foot intervals above the last measurement. Two diameters at right angles were measured at each point. Diameters inside the bark were obtained by measuring the bark thickness with a Swedish bark-measuring instrument. These diameter measurements were plotted directly in the field on U. S. D. A. Forest Service Tree Measurement Form 558a.

Cordwood Measurements

To obtain the solid contents of stacked pulpwood for converting the volume in cubic feet to volume in cords, trees were cut into 8-foot bolts and piled in 2x8x8-foot ricks. Six stacks of this size, the equivalent of six standard cords, were measured. The diameter outside of bark at the middle of each bolt was

[1] The study was carried on in co-operation with the Lake States Forest Experiment Station.

measured with calipers and the length was measured with a tape. Bark thickness was measured with a Swedish bark-measuring instrument. The diameter breast high of the tree from which each bolt was taken was recorded with each bolt measurement.

METHOD OF COMPILATION

Volume Tables

The volume in cubic feet of each tree was obtained by the planimeter method. The tables were made from these volumes by the alinement chart method.[2] For making cubic foot volume tables, this method consists in modifying the scale graduations of a cylinder volume alinement chart so the graduations represent the actual tree volumes.

Reliable volume tables can be made by this method with comparatively few trees, since the entire sample of data is used as the basis of a single curve. This curve usually approximates a straight line. Reliable extensions can therefore be made beyond the limits of the data.

Cordwood Converting Factors

To obtain the cordwood converting factors, the solid contents of each cord was determined by computing the volumes of the bolts by Huber's formula and totaling them.[3] These figures were analyzed to see whether the solid contents of a cord varied with a change in tree diameter. No relation was evident in the data, probably because of the limited range of diameters in the stand and the small number of stacks measured.

The average bolt diameter, solid contents, and number of bolts per cord (Table I) obtained from the six cords were then compared with similar data obtained by H. L. Churchill[4] for Adirondack spruce, to see if these figures could be applied to black spruce. The comparison showed a difference in solid contents and number of bolts of less than 1.5 per cent. This difference could easily have resulted from slight differences in piling. The converting factors for Eastern spruce, in combination with the

[2] Bruce, D., and Reineke, L., of the U.S.D.A. Forest Service, private communication.

[3] Volume in cubic feet is equal to the sectional area at the middle of the bolt in square feet multiplied by the length in feet.

[4] Chapman, H. H. "Forest mensuration." Table XXIV, p. 131. 1924.

average middle diameters of 8-foot bolts for trees of different sizes obtained from the original tree measurements, were therefore used to obtain the converting factors based on tree diameter. (See Table VI for the converting factors.)

TABLE I

AVERAGE DIAMETER BREAST HIGH OF TREES, BOLT DIAMETER, AND CONTENTS OF SIX CORDS* OF BLACK SPRUCE PULPWOOD, CLOQUET, MINNESOTA

D.B.H.	Trees per cord	Bolt diam. with bark†	4-foot bolts per cord	Solid contents per cord		Basis cords
				Wood	Wood and bark	
in.		in.		cu. ft.		
6.5	14.5	5.6	121	75	84	6

* Stack 2x8x8 feet, one-half double cord, or the equivalent space of a standard cord.

† Middle diameter.

The volumes in cords in Table VI were obtained by dividing the merchantable volumes in Table V by these converting factors.

Precision of Compilation

To determine how closely the volume tables represent the volumes of the trees from which the tables were made, the average deviation and aggregate difference in per cent were computed for each table. The average deviation in per cent is the average difference between each tree volume and the corresponding table volume expressed as a percentage of the average table volume. For these tables, the average deviation is less than 5 per cent. In other words, the individual tree volumes differ on an average from the table volumes by this percentage. The aggregate difference in per cent is the difference between the total of the actual tree volumes and the total of the corresponding table volumes as a percentage of the total of the table volumes. In the case of each table this error is less than 0.1 per cent. The specific percentages will be found in the footnotes of each table. These percentages show that the tables represent very closely the tree volumes from which they were made.

TABLE II

BLACK SPRUCE

(Picea mariana)

PEELED TOTAL STEM VOLUME*

R. M. Brown, R. Knudson — Minnesota, 1928 — I. Taylor, T. Lotti

Diameter breast high	Total height of tree—feet								Basis
	30	35	40	45	50	55	60	65	
Inches	Volume—cu. ft.								Trees
3									4
4	1.3	1.5	1.8	2.0	2.2				18
5	2.1	2.4	2.8	3.1	3.4	3.8			16
6		3.5	3.9	4.4	4.8	5.3	5.7	6.2	20
7			5.2	5.8	6.4	7.0	7.6	8.2	19
8			6.7	7.5	8.2	9.0	9.7	10.5	10
9				9.2	10.0	11.0	12.0	13.0	4
10				11.5	12.5	13.5	14.5	16.0	
11					15.0	16.0	17.5	19.0	
12					17.5	19.0	20.5	22.0	
Basis	1	2	8	12	22	21	19	6	91

* Volume includes stump, stem, and top without bark.

Data collected in 1928 by I. Taylor and T. Lotti.

Block indicates the range of basic data.

Average deviation of individual tree volumes from table volumes, ± 4.4 per cent.

Difference between sum of basic volumes and sum of corresponding table volumes, 0.02 per cent of table volumes.

TABLE III

BLACK SPRUCE

(Picea mariana)

UNPEELED TOTAL STEM VOLUME*

R. M. Brown, R. Knudson — Minnesota, 1928 — I. Taylor, T. Lotti

Diameter breast high	Total height of tree—feet								Basis
	30	35	40	45	50	55	60	65	
Inches	Volume—cu. ft.								Trees
3									4
4	1.5	1.7	2.0	2.3	2.5				18
5	2.4	2.7	3.1	3.5	3.8	4.2			16
6		3.9	4.4	4.9	5.4	5.9	6.4	6.9	20
7			5.8	6.5	7.2	7.9	8.5	9.2	19
8			7.5	8.3	9.2	10.0	11.0	11.5	10
9				10.5	11.5	12.5	13.5	14.5	4
10				12.5	14.0	15.0	16.5	17.5	
11						18.0	19.5	21.0	
12						21.0	23.0	25.0	
Basis	1	2	8	12	22	21	19	6	91

* Volume includes stump, stem, and top with bark.

Data collected in 1928 by I. Taylor and T. Lotti.

Block indicates the range of basic data.

Average deviation of individual tree volumes from table volumes, ± 3.7 per cent.

Difference between sum of basic volumes and sum of corresponding table volumes, 0.05 per cent of table volumes.

TABLE IV

BLACK SPRUCE

(Picea mariana)

PEELED MERCHANTABLE VOLUME*

R. M. Brown, R. Knudson — Minnesota, 1928 — I. Taylor, T. Lotti

Diameter breast high	Total height of tree—feet								Basis
	30	35	40	45	50	55	60	65	
Inches	Volume—cu. ft.								Trees
4	.9	1.1	1.4	1.7	1.9				18
5	1.8	2.2	2.6	2.9	3.3	3.6			16
6		3.3	3.9	4.4	4.9	5.4	5.8	6.3	20
7			5.3	5.9	6.6	7.2	7.8	8.5	19
8			6.8	7.6	8.4	9.2	10.0	11.0	10
9				9.6	10.5	11.6	12.5	13.5	4
10				11.5	13.0	14.0	15.5	16.5	
11					15.5	17.0	18.5	20.0	
12					18.0	20.0	21.5	23.5	
Basis			7	12	22	21	19	6	87

* Volume includes the stem without bark above a 1-foot stump to a 3-inch top diameter inside of bark.

Data collected in 1928 by I. Taylor and T. Lotti.

Block indicates the range of basic data.

Average deviation of individual tree volumes from table volumes, ± 4.6 per cent.

Difference between sum of basic volumes and sum of corresponding table volumes, ±0.04 per cent of table volumes.

TABLF V

BLACK SPRUCE

(Picea mariana)

UNPEELED MERCHANTABLE VOLUME*

R. M. Brown, R. Knudson — Minnesota, 1928 — I. Taylor, T. Lotti

Diameter breast high	Total height of tree—feet								Basis
	30	35	40	45	50	55	60	65	
Inches	Volume—cu. ft.								Trees
4	.8	1.0	1.2	1.5	1.7				18
5	1.6	1.9	2.3	2.6	3.0	3.3			16
6		3.0	3.5	3.9	4.4	4.8	5.2	5.7	20
7			4.8	5.3	5.9	6.5	7 0	7.6	19
8			6.1	6.8	7.6	8.3	9.0	9.8	10
9				8.6	9.5	10.5	11.5	12.5	4
10				10.5	11.5	13.0	14.0	15.0	
11					14.5	15.0	16.5	18.0	
12					16.5	18.0	19.5	21.0	
Basis			7	12	22	21	19	6	87

* Volume includes the stem with bark above a 1-foot stump to a 3-inch top diameter inside of bark.

Data collected in 1928 by I. Taylor and T. Lotti.

Block indicates the range of basic data.

Average deviation of individual tree volumes from table volumes, ± 4.4 per cent.

Difference between sum of basic volumes and sum of corresponding table volumes, 0.01 per cent of table volumes.

TABLE VI

BLACK SPRUCE

(Picea mariana)

UNPEELED MERCHANTABLE VOLUME*

(Standard cords, 4×4×8 ft.)

R. M. Brown, R. Knudson — Minnesota, 1928 — I. Taylor, T. Lotti

Diameter breast high	Total height of tree—feet								Basis	Cordwood Converting Factors
	30	35	40	45	50	55	60	65		
Inches	Volume—cords								Trees	cu. ft.
4	.012	.014	.018	.022	.024				18	78
5	.022	.027	.032	.035	.040	.044			16	82
6		.039	.046	.052	.058	.064	.069	.075	20	84
7			.062	.069	.077	.084	.091	.099	19	86
8			.078	.087	.097	.105	.115	.125	10	87
9				.110	.120	.130	.140	.155	4	88
10				.130	.145	.155	.175	.185		89
11					.170	.190	.205	.220		90
12					.200	.220	.240	.260		90
Basis			7	12	22	21	19	6	87	

* Volume includes the stem with bark above a 1-foot stump to a 3-inch top diameter inside of bark.

Volumes computed from unpeeled merchantable table by dividing by the converting factors given in the last column of the table.

Data collected in 1928 by I. Taylor and T. Lotti.

Block indicates the range of basic data.

Average deviation of individual tree volumes from table volumes, ± 4.4 per cent.

Aggregate difference, 0.01 per cent.

PRECAUTIONS TO BE TAKEN IN THE APPLICATION OF THE TABLES IN TIMBER ESTIMATING

The following precautions must be observed in the application of any volume table.

Applicability Check

The failure of the average volumes of given diameter and height classes of a volume table to correspond with the average volumes of the trees of the same sizes in the stand to be estimated is a common source of error in timber estimating. A volume table based on tree volumes from one locality should never be

applied to stands in another locality before it has been checked against tree volumes obtained from the stands to be estimated. This comparison of the table volumes with the actual volumes of the trees in the stand to be estimated is known as the *applicability check.*

The procedure in making this check is as follows:[5]

"In checking the applicability of volume tables, a relatively small number of trees may be used. If their aggregate difference and average deviation from the table be calculated, the test for satisfactory accuracy is:

"(1) An average deviation of the same order of magnitude as that of the basic data on which the table was prepared.

"(2) An aggregate difference which does not exceed two times this average deviation (a.d.) divided by the square root of the number (n) of the trees used in the test."

Algebraically this may be written as follows: Aggregate difference of test sample should be equal to or less than $\frac{2(a.d.)}{\sqrt{n}}$ Where a.d. is the average deviation of the table to be tested (for these tables use 4 per cent) and n is the number of trees in the test sample taken in the stand to be estimated.

The method of making the applicability check can best be illustrated by an example.

1. In the black spruce stands to which the tables are to be applied, obtain diameter measurements inside and outside of the bark on not less than 15 trees. The diameter breast high and the total heights of the test trees should cover the range of heights and diameters and also the range of volumes of the trees in the stand. Measure the diameters at the points given under tree measurements on page 3. Record on U. S. D. A. Form 558 when possible.

2. Compute the unpeeled total stem volume in cubic feet, preferably by the planimeter method, or by the conventional formula method.

3. Tabulate the diameter breast high (D.B.H.), total height, and actual tree volume as shown in Table VII.

[5] Committee Report. Method of preparing volume and yield tables. Jour. For. 24, pp. 653-666. 1926.

TABLE VII

TEST SAMPLE ILLUSTRATING METHOD OF MAKING APPLICABILITY CHECK

Tree No.	D.B.H.	Total height	Unpeeled total volume		Difference
			Actual	Tabular	
	in.	ft.	Cubic feet		Cubic feet
1	9.3	63	15.6	15.2	0.4
2	6.5	58	6.8	7.2	0.4
3	7.3	62	9.6	9.5	0.1
4	8.6	56	12.0	11.8	0.2
5	5.9	54	5.5	5.6	0.1
6	6.3	56	6.9	6.6	0.3
7	4.0	42	2.0	2.1	0.1
8	7.8	54	9.5	9.4	0.1
9	7.0	58	8.0	8.2	0.8
10	6.6	52	6.6	6.7	0.1
11	8.9	63	13.7	13.9	0.2
12	8.6	66	14.0	13.5	0.5
13	4.7	52	3.7	3.6	0.1
14	8.1	58	10.7	10.7	0.0
15	7.2	60	8.8	9.0	0.2
16	5.5	52	5.1	4.8	0.3
Total	...	..	138.5	137.8	3.9

$$\text{Aggregate difference} = 100\,\frac{(138.5-137.8)}{137.8} = 0.5 \text{ per cent.}$$

$$\text{Average deviation} = 100\,\frac{(3.9)}{137.8} = 3 \text{ per cent.}$$

4. For each tree in the test sample, determine the tabular volume (unpeeled total stem volume) corresponding to the actual diameter, to the nearest tenth of an inch, and the actual height to the nearest foot. This can most easily be done by using the volume table in alinement form, Figure 1. The volume of a tree of given diameter and height can be read very easily by placing a transparent straight edge across the axes as illustrated by the dotted line, i.e., the unpeeled total stem volume of a tree 9.3 inches in diameter breast high and 63 feet in height is 15.2 cubic feet as read from the volume axis.

5. Compute the aggregate difference of the trees in the test sample as follows: Take the difference between the sum of the tree volumes and the sum of the tabular volumes and express this as a percentage of the sum of the table volumes. This aggregate difference or percentage of error should be less than the value determined by the formula $\frac{(2)\,(a.d.)}{\sqrt{n}}$. In the assumed test sam-

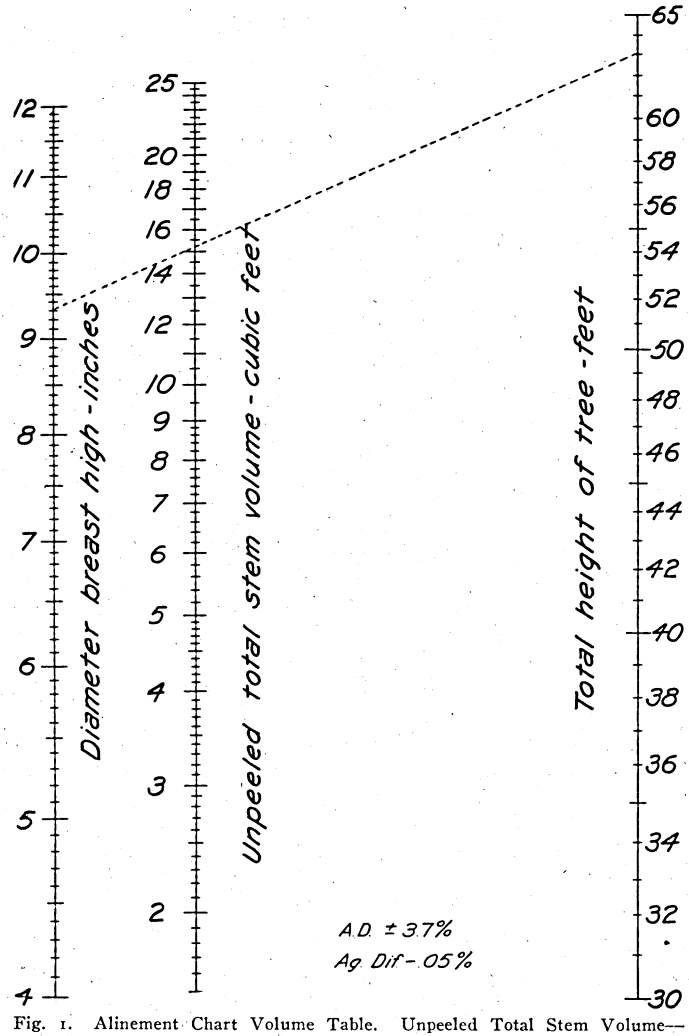

Fig. 1. Alinement Chart Volume Table. Unpeeled Total Stem Volume—Cubic Feet

The dotted line illustrates the method of reading the volume for a given D.B.H. and height.

ple the total volume of the sixteen trees is 138.5 cubic feet and the total of the corresponding volumes read from the chart is 137.8 cubic feet. The volume table therefore underscales the actual tree volumes by 0.5 per cent of the sum of the table volumes. The aggregate difference of the test sample is therefore 0.5 per cent and in this case is less than the value (2 per cent) obtained from the formula $\frac{2x4}{\sqrt{16}}$.

When checking these tables use the formula $\frac{8}{\sqrt{n}}$

6. Compute the average deviation of the volumes of the trees in the test sample as follows: Take the difference between each actual and each tabular volume as shown in the last column in Table VII. Total these differences, regardless of sign, and express this total as a percentage of the sum of the table volumes. This is the average deviation in per cent which should be approximately equal to or less than the average deviation (4 per cent) of the table for a satisfactory check. The average deviation of the test sample, taken as an illustration, is computed by expressing the sum (3.9 cubic feet) of the differences as a percentage of 137.8 cubic feet. This is an average deviation of 3 per cent, which is less than the average deviation of the volume table.

The applicability check of the assumed test sample shows that the volume table scales the volumes of the trees in the sample within the accepted limits of error. The average deviation of the sample was also found to agree with that of the table. One would conclude, therefore, that these tables are suitable without correction for estimating the stand of black spruce from which the assumed sample was taken without introducing an error due to the inapplicability of the volume tables.

METHOD OF CORRECTING THE TABLE IF THE VARIATION EXCEEDS THE ACCEPTED LIMITS[6]

If the applicability check shows that the average deviation and aggregate difference in per cent exceed the accepted limits, the tables may be corrected as follows: Group the tabular volumes in one-foot volume classes, i.e., all trees having a table volume from 0 to 1.9 are placed in the one-foot volume class; those from 2.0 to 2.9 are placed in the two-foot volume class, etc. For each

[6] This procedure is a step in the alinement chart method of making volume tables.

class compute the average tabular volume and the average of the corresponding test-tree volumes. When a sample containing 15 trees is used, grouping is not necessary. On logarithmic cross-section paper plot the average actual tree volumes over the corresponding average table volumes. (Fig. 2.) Balance a curve or straight line[7] in among these averages, and from this curve read the corrected volume for each volume found in the uncorrected table. For example, the corrected volume for a 6-inch 50-foot tree would be read from the above curve over a table volume on the horizontal axes of 5.4 cubic feet, i.e., the volume of a tree of that size found in Table III. (See dotted line in Fig. 2.)

The corrected peeled total and merchantable volume tables can be obtained from the uncorrected unpeeled total stem volume table by a similar procedure. Compute the peeled total stem and merchantable volumes for each tree in the test sample. By a procedure similar to that above classify, average, plot, and curve each series of volumes on the basis of the uncorrected unpeeled total stem volume. To insure consistent results between inside and outside bark volumes and between total and merchantable volumes these curves should be compared with each other by percentages. From this series of curves, read the corrected peeled total and merchantable volumes. The corrected volume table in cords can be obtained by dividing the corrected unpeeled merchantable volumes in cubic feet by the converting factors given in the uncorrected table.

Merchantable Limits

When the merchantable volume tables are used in estimating, allowances should be made if the top cutting limits in the table do not agree with the limits to which the trees will be cut.

Deductions for Defect

No deductions for defect have been made in these tables. In applying them, deductions should be made to obtain the net volume.

Volume of a Single Tree

The average volumes given in a volume table represent a series of volumes that differ one from another. These differences are compensating only when a table is applied to a relatively large

[7] A straight line through the origin (1.1) at 45 degrees indicates that no correction is necessary.

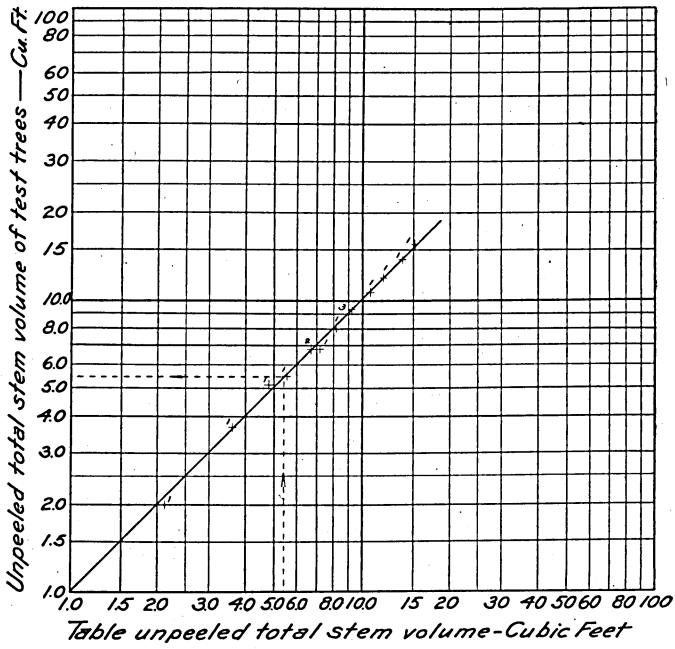

Fig. 2. Method of Adjusting Volumes in Tables by Means of Volumes of Test Trees

The dotted line illustrates the method of reading the corrected volume for a 6-inch 50-foot tree. (The closeness with which the line approaches a 45-degree line through the origin shows that a correction is not necessary in the example cited.)

number of trees in a stand to which the table is applicable. The average deviation indicates that the volume of a single tree, taken at random in a stand to which the tables are applicable, may differ, on the average, from the table volumes by 4 per cent. In some instances the volume of a single tree may vary from the table volumes by as much as 15 per cent. For these reasons, the volume of a single tree can not be accurately determined by these volume tables.

If the above precautions are taken and the tables are checked and adjusted when necessary they can be used to estimate black spruce stands under any conditions.